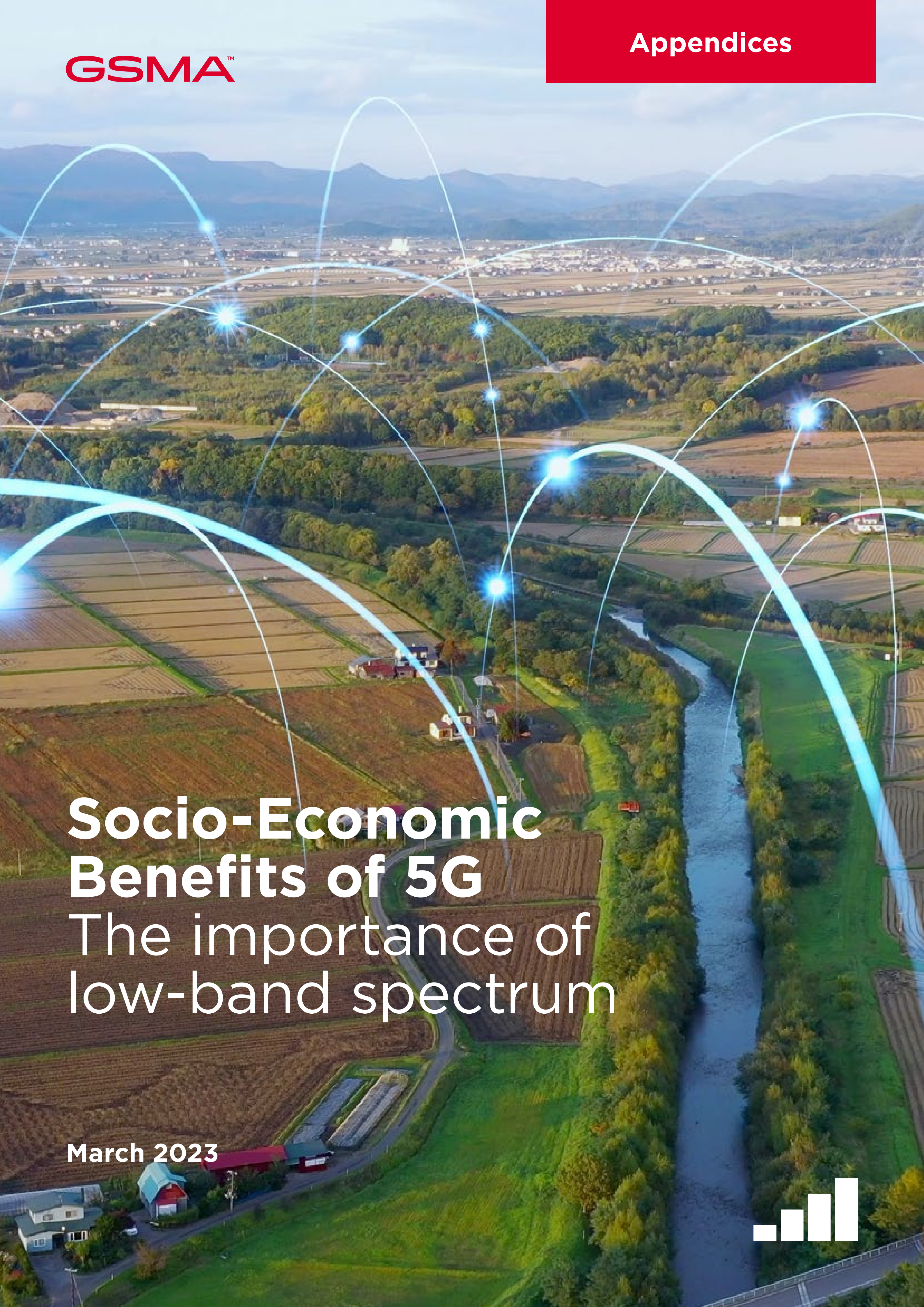

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Appendices

Socio-Economic Benefits of 5G

The importance of low-band spectrum

March 2023

GSMA

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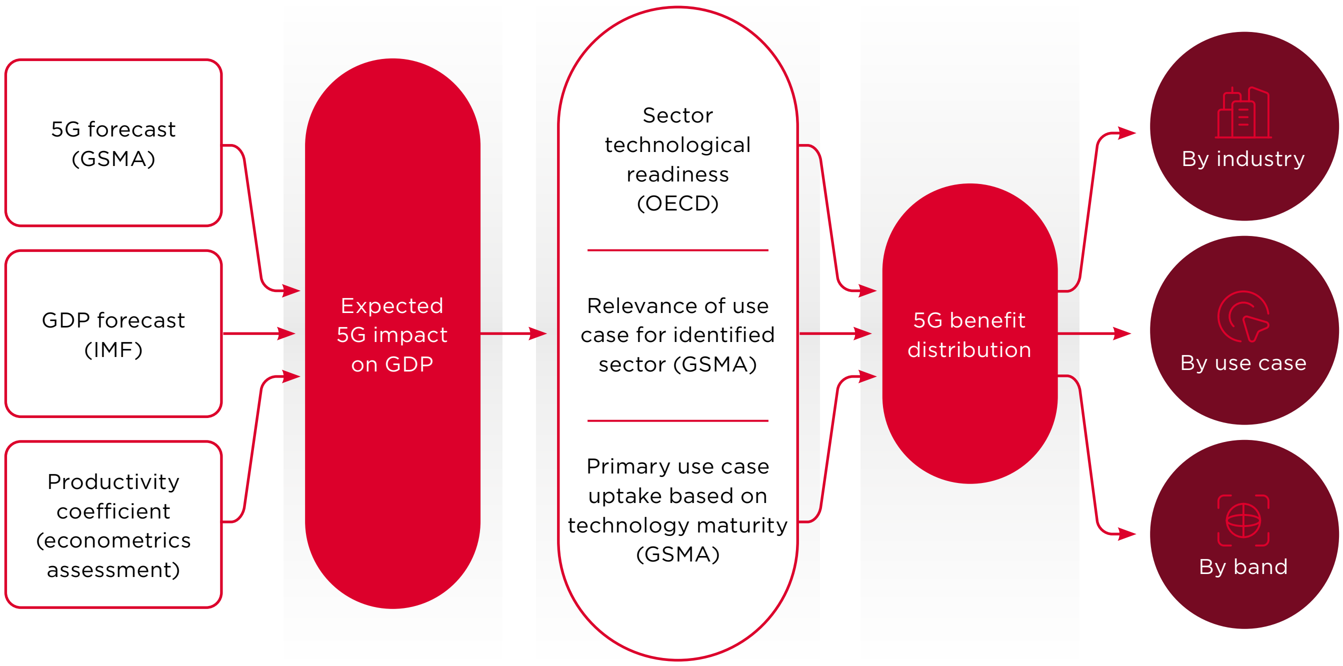
Appendix 1:
Modelling the economic impacts of low-band 5G

The model underpinning the economic impacts of low band is designed to assess the benefits of implementing 5G technology over low-band spectrum across the globe during the 2020–2030 period.

The model is built on two segments: first, it models the impact of 5G-based technologies on productivity and economic growth. Second, it distributes the benefits across sectors based on a number of elements, including the sector's readiness for technology and the expected impact of 5G technologies on the sector. Together, the two segments allow the model to forecast the impact on each sector of the economy.

Figure A1:
High-level overview of methodology



Source: GSMA Intelligence

Economic impact of 5G on GDP

To predict the macroeconomic impact of 5G technology on GDP, we assume that the transition from existing network technologies (primarily 4G) to 5G will deliver an economic impact per mobile connection of a similar magnitude to that delivered by previous technology transitions.

An econometric study,[1] based on the most comprehensive dataset used to date and covering the rollouts of 2G, 3G and 4G globally, finds that on average a 10% increase in mobile adoption increases GDP by 0.5–1.2%. Importantly for our analysis, it also finds that the economic impact of mobile adoption increases by approximately 15% when connections upgrade from 2G to 3G and from 3G to 4G. As a consequence, the higher the mobile technology adoption, the higher the benefit with respect to GDP.

We therefore assume that the transition from 4G to 5G will deliver macroeconomic impacts per connection on GDP of a similar magnitude to those delivered by the transition from 3G to 4G, adjusting for differences in the adoption of each technology – that is, the economic impacts of a connection on 4G increase by 15% for each connection that transitions to 5G.

The benefit at a country level is calculated as a function of the 5G penetration rate, as follows:

t = time

i = country

α = 5G penetration rate

β = 5G productivity impact

$\textit{Total Benefit}_{it} = \textit{GDP}_{it} * (\alpha_{it} - \alpha_{it-1}) * \beta$

For most of the developed economies, the α parameter is based on the 5G long-term forecast, while for the β parameter, the model assumes a GDP increase of 0.08% to 0.2% for every 10% increase in 5G connections uptake. This value is calculated based on the results of the GSMA Intelligence working paper.[2]

Technology readiness by sector

Each economic sector of a country is assigned a score based on its readiness to adopt technology, with 0 the lowest readiness and 5 the highest readiness and aptitude to benefit from mobile technology adoption compared to other sectors. For example, the agricultural sector has the lowest score, indicating that the sector is generally not well placed to adopt new technology. In contrast, technology-intensive sectors, such as finance and information & communication, are characterised by a higher score.

Scores are informed by the results of the OECD Science, Technology and Industry Scoreboard studies[3] to identify the sectors most prone to technological innovation, with particular reference to the mobile sector.

Figure A2:
Technology readiness coefficient, by sector

Sector	Score (OECD average)
Agriculture	**1.3**
Construction and real estate	**1.6**
Accommodation and food	**2.0**
Utilities	**2.0**
Transport	**2.3**
Oil and gas	**2.3**
Education	**2.4**
Public administration	**2.6**
Healthcare	**2.8**
Arts, entertainment and recreation	**3.0**
Manufacturing	**3.1**
Retail	**3.2**
Services	**3.3**
Finance	**3.6**
Information and communication	**3.8**

Source: OECD 2018

1 Mobile technology: two decades driving economic growth, Working Paper, GSMA Intelligence, 2020
2 Mobile technology: two decades driving economic growth, Working Paper, GSMA Intelligence, 2020
3 A taxonomy of digital intensive sectors, F. Calvino, C. Criscuolo, L. Marcolin and M. Squicciarini, 2018

Relevance of 5G use cases by sector

5G use cases are classified into four main groups, as shown in Figure A3.

Figure A3:
5G use cases

Primary use case	Example applications
Enhanced mobile broadband (eMBB)	Data-intensive mobile connectivity
	AR/VR
	Broadband for public transport
Fixed wireless access (FWA)	Ultra-low-cost networks in rural areas
	Dynamic hotspots
	Stationary or near-stationary monitoring networks
Ultra-reliable, low-latency communications (URLLC)	Connected vehicles
	Edge computing
	Industrial automation
Massive Internet of Things (mIoT)	Remote object manipulation
	Precision agriculture
	Predictive maintenance

Source: GSMA Intelligence

Using input provided by a panel of GSMA 5G experts, we associate a score for each use case, based on its relevance to the sector, assigning a score of 0 in the case of no relevance and 6 in the case of maximum relevance. For example, URLLC is considered of limited relevance to the agricultural sector (low score) but very relevant to the manufacturing, utilities and financial sectors (high scores).

The model considers different use cases that are responsible for the 5G economic benefit in each sector. Some use cases will be ready to be implemented earlier than others. The scores are therefore adjusted to reflect changes over time to the potential impacts of each use case.

Figure A4:
Sector use case matrix, 2020–2030

Sector	eMBB	FWA	mIoT	URLLC
Agriculture, forestry and fishing	5	5	4	1
Construction and real estate	3	3	3	2
Accommodation and food service activities	5	5	2	0
Utilities	3	3	3	4
Transportation and storage	4	2	4	4
Mining and quarrying	5	5	4	3
Education	6	6	0	4
Public administration and defence; compulsory social security	5	5	4	3
Human health and social work activities	5	5	2	4
Arts, entertainment and recreation	6	6	0	0
Manufacturing	6	6	4	4
Retail	5	5	4	2
Services	6	6	0	0
Financial and insurance activities	5	5	0	4
Information and communication	6	6	3	3

Source: GSMA Intelligence

Distributing 5G benefits between spectrum bands

The study focuses on the benefits of 5G associated with low bands – one of three ranges (together with mid- and high bands) suitable to provide 5G services.

To quantify low band as a share of the total benefits, we looked at the relevance of each band for the deployment of the four main 5G use cases.

Figure A5:
5G use cases and spectrum band relevance

Application	Low band	Mid-band	mmWave band
eMBB	10%	80%	10%
FWA	10%	60%	30%
mIoT	40%	60%	0%
URLLC	0%	40%	60%

Source: GSMA Intelligence

The coefficients presented in Figure A5 have been informed by the following.

Looking at the four main 5G use cases, for the period 2020–2030, it is expected that eMBB and FWA will be responsible for the greatest share of the total benefits, as mIoT and URLLC associated applications are still in a premature stage of development.

Over the period 2020–2030, eMBB applications (multimedia access, streaming, email, HD video calling) are expected to be mostly based on the use of mid-band spectrum, as the band provides a balance of coverage and capacity.

For FWA, mid-band spectrum is also expected to play the greatest role, though pilot projects on the use of mmWave bands to deploy FWA in suburban and rural areas suggest mmWave may play a greater role in the future.

mIoT applications encompass smart readers, smart sensors and all IoT devices that are expected to be deployed, for example, in smart cities. For mIoT, coverage will be an important aspect, hence the relevance of low bands (as well as mid-bands) for this type of application.

For URLLC, encompassing new applications requiring extremely low latency and high bandwidth (for example, smart robots, smart manufacturing devices and remote object manipulation), mid-bands and high bands are expected to be the main bands used, given their low latency and high capacity.

Appendix 2:
Cost-benefit analysis methodology

Approach to cost-benefit analysis (CBA)

When considering the use of UHF spectrum for either broadcasting or mobile services, we estimate the cost and benefit net present value (NPV) between 2021 and 2040.

As the policy being assessed is whether to reallocate spectrum from broadcasting (existing use) to mobile (new use), the main benefit from assigning additional low-band spectrum to provide wireless connectivity is that it can make it less costly to deploy 5G networks in order to meet capacity and coverage requirements. In economic terms, this is represented by a shift in the supply curve. The availability of additional sub-1 GHz spectrum will give operators significant cost savings to be able to add capacity to their 5G networks and extend coverage without having to incur additional opex and capex investment, therefore avoiding any potential pass-through price increases for consumers or quality-of-service degradation.

On the other side, the costs are primarily related to repurposing DTT and PMSE services,[4] which currently operate in the UHF band in ITU Region 1. For this estimation, the objective is to assess the costs of repurposing such that the consumer and DTT providers can maintain the same level of broadcast output in terms of national, regional and local TV programmes. This is known as the 'least cost approach' (LCA). An alternative response to having less spectrum for DTT is that providers may reduce output (i.e. the number of channels), which would lower costs but also revenues. As there is less data available on the revenue side, we focus on the LCA

It is worth noting that, given the declining viewership trends in DTT in most countries, the assumption that the current number of programmes needs to be maintained could be quite conservative. This is especially the case when considering that, in most countries, TV audience market share is dominated by a small number of channels. For example, in the EU, the four leading TV groups accounted on average for 72% of daily audience market share in 2021, with that number increasing to more than 80% in many markets.[5]

Regulators in each country would have to consider the costs and benefits for their respective mobile and broadcasting sectors and gather the appropriate economic and technical inputs.[6] For this study, when applying the CBA framework, we consider five specific 'settings'. The assumptions for each setting are detailed in the sections below, but in general they cover the following:

- **Setting 1** – allocating 80 MHz of UHF spectrum for a typical country in Europe
- **Setting 2** – allocating the full 224 MHz of UHF spectrum for a typical country in Europe
- **Setting 3** – allocating 80 MHz of UHF spectrum for a typical country in the Middle East
- **Setting 4** – allocating the full 224 MHz of UHF spectrum for a typical country in the Middle East
- **Setting 5** – allocating 80 MHz of UHF spectrum for a typical country in Africa.

4 Programme Making and Special Events (PMSE) equipment includes wireless microphones, in-ear monitors and audio links. The equipment typically uses spectrum for a short-term at a particular time and location (for example at outdoor events), though some uses are more continuous (for example in television studios). It uses spectrum in TV white spaces – that is, spectrum in the 470–694 MHz band that is not being utilised locally. The other secondary user of the spectrum is radio astronomy, which uses a narrow 5 MHz band in the 600 MHz allocation.

5 European Audiovisual Observatory

6 Previous CBAs have been carried out for the 700 MHz band. See for example Decision to make the 700 MHz band available for mobile data, Ofcom, 2014; and The 700 MHz radio frequency band: Results of the Cost Benefit Analysis (CBA) of a change in use of the 700 MHz radio frequency band in Ireland, Comreg, 2015.

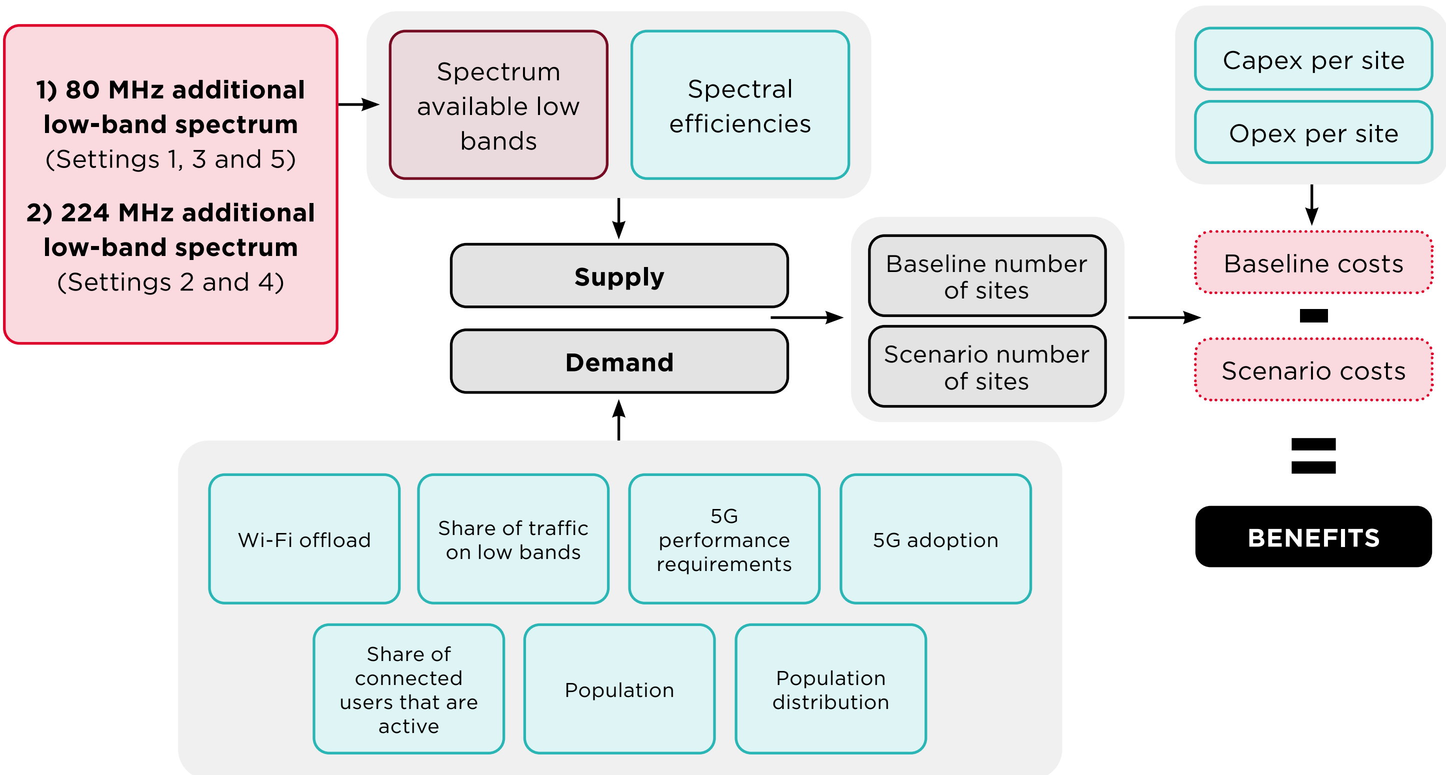
Assessing the cost-saving benefits for 5G mobile broadband services

To quantify the direct benefits of mobile operators in having additional low-band spectrum to address demand driven by the growth of 5G penetration, we estimate the number of sites needed to meet the ITU Requirements for IMT-2020,[7] specifically 100 Mbps on downlink and 50 Mbps on uplink in urban areas. For rural areas, we assume 5G performance requirements of 20 Mbps on downlink and 10 Mbps on uplink. For each setting, two scenarios are estimated. The first – 'Baseline' – assumes that operators have access to 190 MHz in sub-1 GHz bands for the entire period evaluated. The second – 'Scenario' – assumes that an additional 80 MHz of spectrum in the UHF band is allocated to operators so that they have a total of 270 MHz in low bands in Settings 1/3/5, while for Settings 2/4 we assume an additional 224 MHz of spectrum is allocated to operators, such that they have a total of 414 MHz.

When estimating the number of sites, we distinguish between urban and rural areas, since the conditions of deployment are different. In urban areas, we estimate the number of macro-sites that are needed to meet traffic that can only be served by low-band spectrum (e.g. coverage in deep indoor and built-up areas). It is therefore purely capacity driven. In rural areas, we estimate the number of sites needed to cover 99% of the population and to deliver the selected performance requirement. It is therefore both coverage and capacity driven. The difference in the cost of sites required to meet demand in the two cases (Baseline and Scenario) are the associated benefits for assigning additional UHF spectrum for mobile.

Once the total infrastructure costs at sites required to support the total demand in each of the years have been calculated, the difference or savings in NPV between the two scenarios (baseline and scenario) is calculated with a social discount rate of 3.5%. The following tables summarise the methodology and assumptions used in modelling cost savings for mobile operators.

Figure A6:
Cost savings approach of having additional spectrum in the UHF band



Source: GSMA Intelligence

7 Report ITU-R M.2441, Emerging usage of the terrestrial component of International Mobile Telecommunication (IMT) and Report ITU-R M.2410, Minimum requirements related to technical performance for IMT-2020 radio interface(s)

Figure A7:
Mobile technical and spectrum assumptions

Assumption	Value	Source
Supply factors		
Low-band spectrum available in baseline	190 MHz	3GPP sub-1GHz bands in ITU region 1[8]
Low-band spectrum available in scenario	270 MHz in Settings 1/3/5 414 MHz in Settings 2/4	In Settings 1/3/5, we assume an additional 80 MHz spectrum in the 614–694 MHz range. In Settings 2/4, we assume an additional 224 MHz spectrum in the 470–694 MHz range.
Share of mobile traffic served by low bands in urban areas	10%	Coleago (2022), Low-band spectrum for 5G The estimated share of traffic on low bands is between 10% and 20%. We use the lower figure to be conservative.
Share of mobile traffic served by low bands in rural areas	50%	Frontier Economics (2015)[9]
Loading factor	85%	GSMA (2022)[10], Analysys Mason (2014)[11] and Frontier Economics (2015)
Low-band spectral efficiency for 5G (downlink and uplink)	1.8 bits/s/Hz We assume that in the long-run all sub-1 GHz spectrum uses 5G	Coleago (2022), Low-band spectrum for 5G
Number of sectors per macro cell	3	GSMA (2022)[12]
Downlink / uplink ratio	1:1	GSMA (2022)[13]
Asset life	10 years	GSMA (2022)[14]
Wi-Fi traffic offload	70% This is a very conservative assumption, as in practice Wi-Fi offload of mobile data is likely to be much less (see GSMA (2022)[15]).	GSMA (2022)[16] based on Cisco estimates
Urban capex and opex per site	$50,000 capex $12,500 opex	Coleago (2021)[17] and Oughton et al (2022)[18]
Rural capex and opex per site	$59,000 capex $14,750 opex Costs are assumed to be 18% higher than in urban areas.	GSMA (2019)[19]

8 For further details, see Low-band spectrum for 5G, Coleago, 2022
9 A cost benefit analysis of the change in use of the 700 MHz radio frequency band in Ireland: A report prepared for Comreg, Frontier Economics, 2015
10 Vision 2030: mmWave Spectrum Needs: Estimating High-Band Spectrum Needs in the 2025-2030 Time Frame, GSMA, 2022
11 Assessment of the benefits of a change of use of the 700MHz band to mobile, Analysys Mason report for Ofcom, 2014
12 Maximising the socio-economic value of spectrum: A best practice guide for the cost-benefit analysis of 5G spectrum assignments, GSMA, 2022
13 Maximising the socio-economic value of spectrum: A best practice guide for the cost-benefit analysis of 5G spectrum assignments, GSMA, 2022
14 Maximising the socio-economic value of spectrum: A best practice guide for the cost-benefit analysis of 5G spectrum assignments, GSMA, 2022
15 The socioeconomic benefits of the 6 GHz band Considering licensed and unlicensed options, GSMA Intelligence, 2022
16 Maximising the socio-economic value of spectrum: A best practice guide for the cost-benefit analysis of 5G spectrum assignments, GSMA, 2022
17 Estimating the mid-band spectrum needs in the 2025-2030 time frame, Coleago, 2021
18 Policy choices can help keep 4G and 5G universal broadband affordable, Technological Forecasting and Social Change Volume 176, Oughton et al, 2022
19 Closing the Coverage Gap: How Innovation Can Drive Rural Connectivity, GSMA, 2019

Assumption	Value	Source
Demand factors		
Urban downlink/ uplink 5G performance requirement	100 Mbps downlink 50 Mbps uplink	ITU-R M.2410-0 (11/2017)
Rural downlink/uplink 5G performance requirement	20 Mbps downlink 5 Mbps uplink	Coleago (2022) suggested that operators are aiming for rural cell edge speeds between 10 and 30 Mbps for 5G. We therefore assume the mid-point.
5G penetration	Settings 1 and 2 – median forecast 5G penetration in Europe in 2021–2040 Settings 3 and 4 – median forecast 5G penetration in Middle East and North Africa in 2021–2040 Setting 5 – median forecast 5G penetration in Sub-Saharan Africa in 2021–2040	GSMA Intelligence forecasts
Activity factor **(this refers to the proportion of 5G connections concurrently active in the peak hour)**	10%	GSMA Intelligence
Urban population	Settings 1 and 2 – median forecast of urban population in Europe 2021–2040. In 2021, this was 6.4 million. Setting 3 and 4 – median forecast of urban population in the Middle East and North Africa 2021–2040. In 2021, this was 10.1 million Setting 5 – median forecast of urban population in Sub-Saharan Africa 2021–2040. In 2021, this was 8.1 million.	UN World Population Prospects and World Bank Forecasts

Assumption	Value	Source
Rural population	Settings 1 and 2 – median forecast of rural population in Europe 2021–2040. In 2021, this was 2.3 million. Setting 3 and 4 – median forecast of the rural population in the Middle East and North Africa 2021–2040. In 2021, this was 1.8 million. Setting 5 – median forecast of the rural population in Sub-Saharan Africa 2021–2040. In 2021, this was 9.9 million.	UN World Population Prospects and World Bank Forecasts
Rural population distribution	This is needed to estimate the number of sites to cover rural populations. We select three countries that are most similar to the urban/ rural population and 5G demand assumptions in the four settings. We then use their population distributions to estimate the number of sites needed to cover rural populations with 5G networks and provide 20 Mbps downlink. The countries are: • Hungary for Settings 1 and 2 • UAE for Settings 3 and 4 • Zambia for Setting 5	European Commission, Global Human Settlement Layer
Cell radius	To estimate the number of sites needed to cover rural populations, the model requires an assumption regarding the typical distance that a macro-site in rural areas can reach. We assume a distance of 8.5 kilometres when using 700 MHz bands (in the Baseline) and 10.5 kilometres when using 600 MHz bands (in the Scenario).	Coleago (2022), Low-band spectrum for 5G and ZTE (2013)[20]

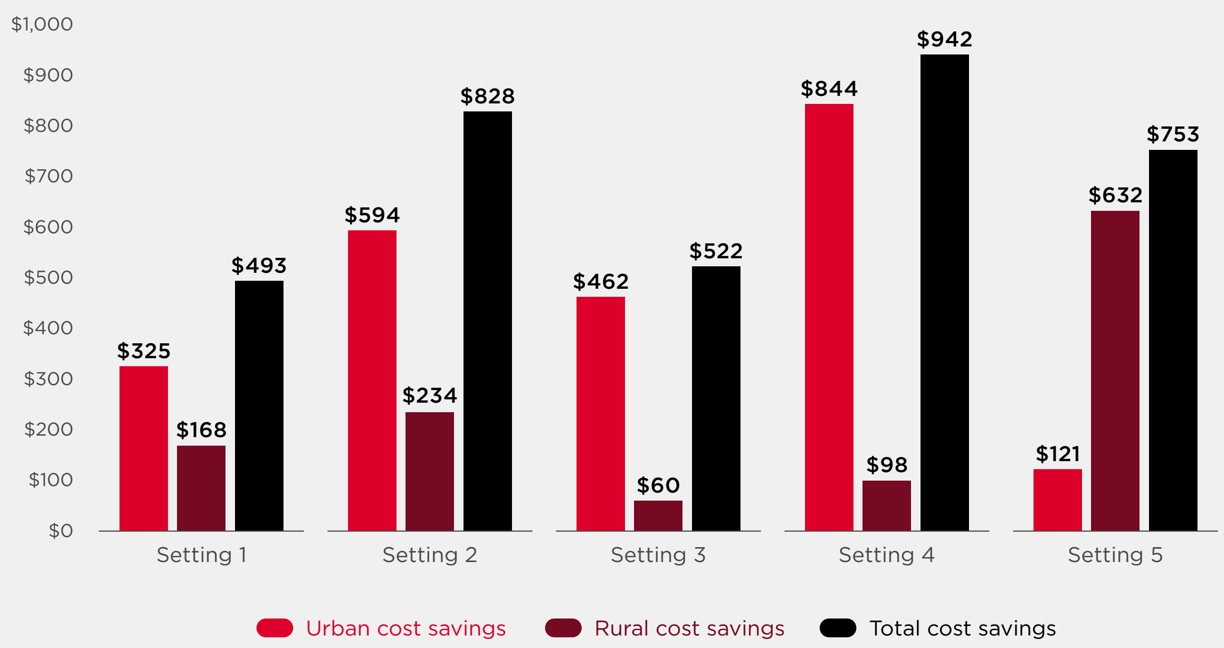
20 APT 700MHz: Best Choice for nationwide coverage, ZTE, 2013

Cost savings for mobile operators from having additional UHF spectrum

As shown in Figure A8, and depending on the Setting considered, we estimate the total savings or benefits to the mobile operators of having 80 MHz in the low bands would be of the order of $490 million and $940 million. The results between urban and rural zones depend primarily on population (total and distribution), 5G penetration and the amount of additional spectrum available.

Figure A8:
Cost savings associated with having additional spectrum in low bands for urban and rural areas

Million



Source: GSMA Intelligence

Assessing the cost to DTT and PSME services of repurposing UHF spectrum

To estimate the DTT and PSME costs associated with repurposing spectrum in the UHF band for mobile, the methodology follows three main stages. First, it estimates the spectrum demand for broadcasters, which depends on the number of multiplexes and programmes (or channels) in the baseline. Second, and after evaluating the spectrum demand for the baseline case, it assesses the technical alternatives or upgrades that broadcasters can implement to keep the same number of programmes with less spectrum. Lastly, the model then estimates the costs associated with implementing the appropriate technical solution. The key broadcast modelling assumptions, including the broadcast characteristics for each setting, are shown in Figure A9.

Figure A9:
Broadcasting technical and spectrum assumptions

Assumption	Value	Source
Number of national multiplexes (muxes) in baseline	Settings 1 and 2: five national muxes. This is the median value for countries in Europe. Setting 3 and 4: four national muxes. This is the median value for countries in the Middle East and North Africa. Setting 5: four national muxes. This is the median value for countries in Sub-Saharan Africa.	VVA and LS Telcom (2022),[21] ITU (2021),[22] and TMG and GSMA (2022)[23]
Number of national multiplexes (muxes) in scenario	We assume that a spectrum reduction of 80 MHz in low bands represents a 35% reduction of available muxes in the scenario Setting 1: four national muxes. Setting 3: three national muxes. Setting 5: three national muxes. Settings 2 and 4: zero national muxes	VVA and LS Telcom (2022), ITU (2021), and TMG (2022)
Number of programmes	Settings 1 and 2: 51 programmes. This is the median value for Europe. Setting 3 and 4: 11 programmes. This is the median value for countries in the Middle East and North Africa. Setting 5: 48 programmes. This is the median value for Sub-Saharan Africa. These include free-to-air and pay-TV programmes, as well as national and regional programmes.	VVA and LS Telcom (2022), ITU (2021), and TMG (2022)

21 VVA and LS Telcom. (2022). Study on the use of the sub-700 MHz band (470-694 MHz). European Commission
22 Spectrum requirements for terrestrial television broadcasting in the UHF frequency band in Region 1 and the Islamic Republic of Iran, ITU, 2021
23 Digital Switchover in Sub-Saharan Africa, GSMA, TMG, 2022

Assumption	Value	Source
HD/SD programme split	Settings 1 and 2: 10 in HD and 41 in SD. This is the median value for Europe. Setting 3 and 4: 11 in HD. This is the median value for the Middle East and North Africa. Setting 5: 10 in HD and 38 in SD. This is the median value for Sub-Saharan Africa. These include free-to-air and pay-TV programmes, as well as national and regional programmes.	VVA and LS Telcom (2022), ITU (2021), and TMG (2022)
Number of broadcasting transmitters	Settings 1 and 2: 229 transmitters. This is the median value for Europe. Settings 3 and 4: 98 transmitters. This is the median value for the Middle East and North Africa. Setting 5: 100 transmitters. This is the median value for Sub-Saharan Africa.	VVA and LS Telcom (2022) and ITU (2021)
Number of households	Settings 1 and 2: 3.1 million households. This is the median value for countries in Europe. Settings 3 and 4: 3.9 million households. This is the median value for the Middle East and North Africa. Setting 5: 3.5 million households. This is the median value for Sub-Saharan Africa.	ITU statistics
Multiplex data rate	DVB-T: 24 Mbps DVB-T2: 40Mbps	ITU (2021) Report ITU-R BT.2302-1
Bandwidth required per programme	SD: 2.2 Mbps (This means DVB-T can carry 10-11 SD programmes and DVB-T2 can carry 18 SD programmes.) HD: 6 Mbps (This means DVB-T can carry 3-4 HD programmes and DVB-T2 can carry 6 HD programmes)	ITU (2021) Report ITU-R BT.2302-1
Video compression	We assume that the video compression technology used is MPEG4 (H.264)	

Following a reduction in the amount of UHF spectrum available for broadcasting and PMSE, the following options are considered:

1. **Move to a reduced band:** In this case, the broadcaster would migrate services in the 600 MHz band to other UHF bands given that even with the loss of spectrum, they can maintain the same number of programmes.
2. **Upgrade to DVB-T2:**[24] Given that DVB-T2 can achieve a higher programme capacity per multiplex, this upgrade allows broadcasters to potentially deliver the same number of programmes with less spectrum.
3. **Upgrade to SFN[25] and DVB-T2:** If, after the implementation of DVB-T2 technology, broadcasters cannot maintain the same number of programmes as the baseline, they could implement a single frequency network (SFN) alternative, which increases the spectrum efficiency of the broadcasting network. We assume that implementing this technology involves adding one additional DVB-T2 multiplex (i.e. one SFN mux, rather than re-planning the entire broadcast network as an SFN, which would be a much more complex undertaking).
4. **Migration to another platform:** After evaluating and implementing the three previous upgrades, if there are still programmes not able to be transmitted, this alternative involves moving the programmes to a satellite broadcasting network. An alternative migration platform would be IPTV, but there is currently insufficient data to assess this option, so we assume migration is to satellite.

The overall approach is summarised in Figure A10. It should be noted that the above are not the only ways broadcasters could respond to a reduction in UHF spectrum. One alternative could be to upgrade to more efficient video compression technologies (e.g. H.265 or H.266), which reduces the capacity required by a service, meaning that more programmes can be carried within the same capacity. Another option would be to operate the entire broadcasting network as a single frequency network (SFN), rather than a multi-frequency network (MFN). In the majority of countries, this should provide sufficient capacity to deliver existing programme output without spectrum in the 614–694 MHz frequency range. However, this would require significantly more complex deployment and network planning, it would severely limit regional programming and would require coordination with neighbouring countries.[26] As we do not have sufficient cost data or network information for a full SFN, we are unable to model this option in our framework, but it is something national regulators could do.

Another option could be to change the broadcasting network topology – for example, using low power, low tower (LPLT) networks or medium power, medium tower (MPMT) networks, rather than high power, high tower (HPHT). The use of HPHT enables coverage of large areas with less equipment (and therefore less cost) but reduces the amount of spectrum reuse. Moving to LPLT or MPMT increases frequency reuse and therefore spectral efficiency.[27] Similar to the 'full SFN' option, we did not have enough information to model this option, but it is an alternative that regulators could consider.

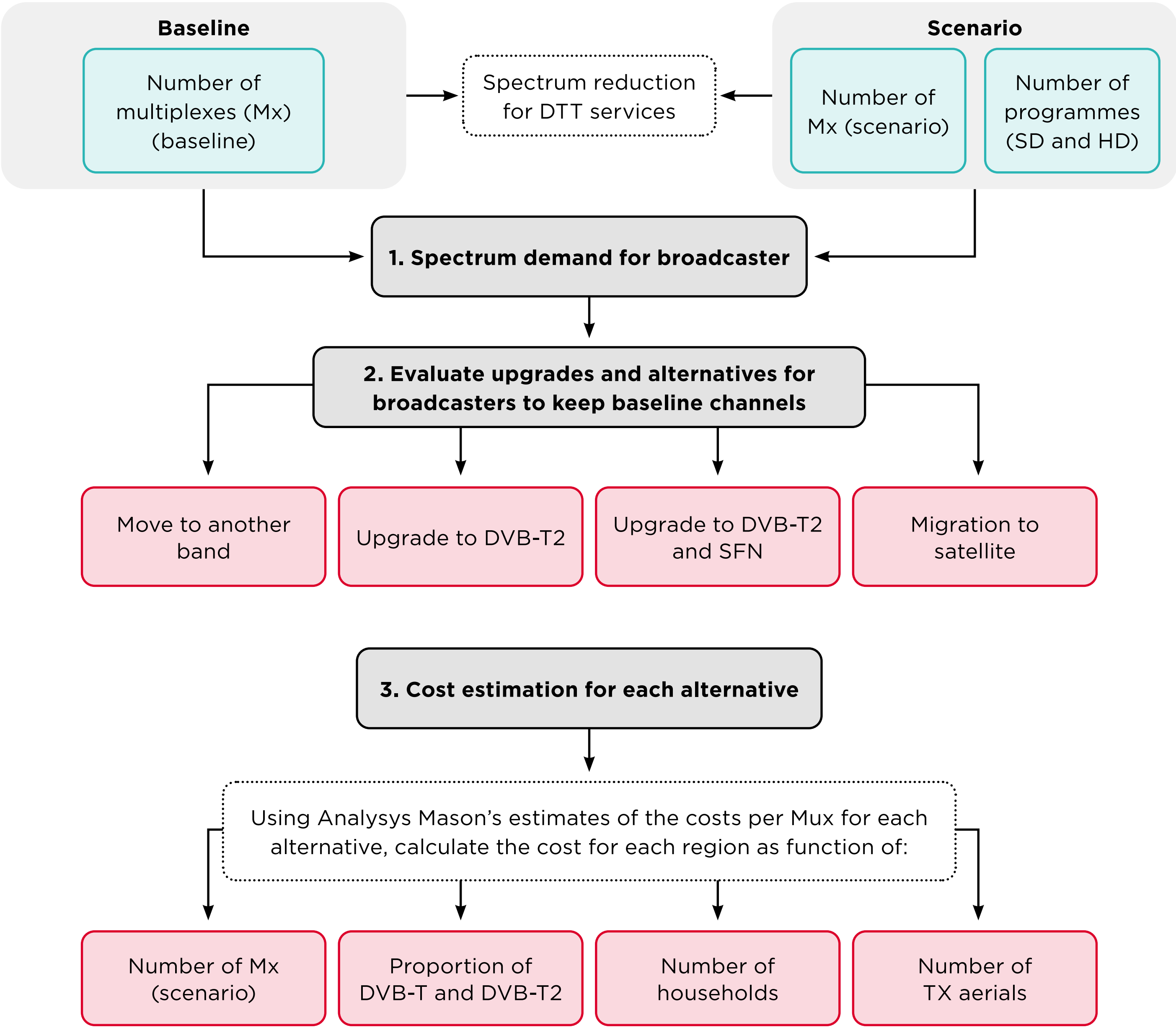
24 DVB-T2 refers to the latest broadcasting transmission standard. The previous standard is DVB-T, which carries less capacity per multiplex. Further details on the assumptions are provided in Appendix 2.

25 Most broadcasting networks in Region 1 are multi-frequency networks (MFNs), where neighbouring transmitter sites broadcast on different frequencies to avoid interference at the receiver. This means that not all available frequencies are used at each tower. In SFNs, the same content is broadcast in the same frequencies in neighbouring cells, thereby enabling greater spectral efficiency.

26 See Study on the use of the sub-700 MHz band (470-694 MHz), European Commission, 2022

27 See Study on the use of the sub-700 MHz band (470-694 MHz), European Commission, 2022

Figure A10:
Broadcast cost methodology and approach



Source: GSMA Intelligence

In order to estimate the implementation costs of each of these options, we used the costs set out in the Analysys Mason study for Ofcom (hereafter referred to as the 'Analysys Mason study') that assessed the opportunity cost of DTT and digital audio broadcasting spectrum in the UK.[28] In particular, it considered the four different responses by the broadcasting sector if they had less UHF spectrum and estimated the cost of each one based on the LCA approach. A list of the costs considered are presented in Figure A11, while the costs are shown in Figure A12. The study considered a four-year duration for managing the different options.

To apply these estimates to our study, we converted the cost per multiplex to US dollars in 2021 (adjusting for inflation as the original costs were based on 2015 prices). Each cost was then split based on costs associated with households (e.g. replacement CPE, domestic aerial changes and publicity) and those associated with the broadcasting network (e.g. re-engineering transmitters, re-planning).

For each Setting, based on what the optimal response is to a reduction in UHF spectrum (move to a reduced band, upgrade to DVB-T2, upgrade one mux to SFN or migrate to satellite), we took the updated 2021 cost from the Analysys Mason study and adjusted the

28 Opportunity cost of the spectrum used by digital terrestrial TV and digital audio broadcasting. Final report for Ofcom. Analysys Mason, Aegis System, 2013

household costs based on the number of households and the transmission costs based on the number of transmitters. For example, in Setting 1, we assume 3.1 million households and 229 transmitters. The UK had around 27 million households in 2021, while the Analysys Mason study was based on 1,160 DTT tower sites operating in the UK. Therefore, for Setting 1, we adjust household costs by a factor of 3.1/27 = 0.11 and we adjust the transmission costs by a factor of 229/1160 = 0.20.

Lastly, we also factored in the use of interleaved spectrum, particularly what is used by programme making and special events (PMSE). Based on the costs of moving PMSE services to an alternative band that were estimated by the Analysys Mason study, we applied the same uplift. For example, if the mitigation costs for PMSE was equal to 1% of the cost of the DTT mitigation cost in the Analysys Mason study, then we apply a 1% uplift to the initial cost.

Figure A11:
Broadcast costs items per upgrade and alternative

Move to another band	Upgrade to DVB-T2	Upgrade to SFN (one Mx)	Migration to satellite
— Costs of domestic aerial changes — Costs of re-engineering TX aerials — Costs of re-planning — Costs associated with publicity	— Cost of replacement CPE — Costs of domestic aerial changes — Costs of re-engineering TXs — Costs of re-engineering TX aerials — Costs of re-planning — Costs associated with publicity — Loss (savings) from transmission	— Cost of replacement CPE — Costs of domestic aerial changes — Costs of re-engineering TXs — Costs of re-engineering TX aerials — Costs of re-planning — Costs associated with publicity — Loss (savings) from transmission	— Cost of household conversion — DTT future costs — DTT future revenues — Costs associated with publicity

Source: Analysys Mason

Figure A12:
DTT and PSME cost assumptions based on Analysys Mason (2013)

Mitigation response	Indicative average annual cost per mux (£ million for 2015)	Indicative average total cost per mux in four years (£ million for 2015)	Total cost (£ million for 2021)	Total cost ($ million for 2021)	Total cost HH ($ million for 2021)	Total cost network ($ million for 2021)	PSME uplift
Switch the DTT platform to a satellite	£52.8	£211.2	£235.7	$324.1	$131.26	$192.88	0.75%
Upgrade muxes to DVB-T2	£19	£76	£84.8	$116.6	$79.93	$36.71	1.7%
Upgrade muxes to SFN and DVB-T2	£21.9	£87.6	£97.7	$134.4	$113.10	$21.34	2.3%
Move channels to the 600 MHz band	£12.1	£48.4	£54.0	$74.3	$58.28	$16.00	2.8%

Source: GSMA Intelligence based on data provided in Analysys Mason study for Ofcom (2013)

Broadcasting costs of repurposing UHF spectrum

Taking into account the characteristic variations in the broadcasting sector for each of the settings, the following summarises the estimated costs of each of the alternatives required to maintain the same channel offered to users:

1. **Setting 1:** Considering that in the baseline there were five multiplexes, of which three had DVB-T2 technology and two with DVB-T, with the spectrum reduction it is assumed that in the scenario there are a total of four multiplexes. To maintain the offer of 51 programmes (10 in HD and 41 in SD), it is necessary to upgrade all multiplexes to DVB-T2 technology. The estimated NPV costs of this alternative are $80 million.
2. **Setting 2:** In this case, it is necessary for the entire DTT platform to close and migrate to another platform. Based on the costs of moving all programmes to satellite, we estimate that moving the five multiplexes and 51 channels to the satellite platform would involve NPV costs of $198 million.
3. **Setting 3:** Considering that in the baseline there were four multiplexes, three with DVB-T2 technology and one with DVB-T, with the spectrum reduction it is assumed that in the scenario there are a total of three multiplexes with DVB-T2 technology. To maintain the offer of 11 programmes in HD, it is then sufficient to move these multiplexes to bands below 600 MHz. The estimated NPV costs of such an alternative are $22 million.
4. **Setting 4:** In this case, it is necessary for the entire DTT platform to close and migrate to another platform. Based on the costs of moving all programmes to satellite, we estimate that moving the four multiplexes and 11 HD channels to the satellite platform would involve NPV costs of $104 million.
5. **Setting 5:** Considering that in the baseline there were four multiplexes, all of them with DVB-T2 technology, with the spectrum reduction it is assumed that in the scenario there are a total of three multiplexes with DVB-T2 technology. To maintain the offer of 48 programmes, it is then necessary to upgrade these multiplexes to a SFN technology. The estimated NPV costs of such an alternative are $58 million.

Figure A13 summarises the results of broadcasting modelling costs and upgrades by setting.

Figure A13:
DTT and PSME final costs for each setting

	Setting 1	Setting 2	Setting 3	Setting 4	Setting 5
Upgrade required	Upgrade to DVB-T2	Migrate to alternative platform	Move to another band	Migrate to satellite	Upgrade to SFN
Costs NPV ($ million)	$80	$198	$22	$104	$58

Source: GSMA Intelligence

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